Astronomy 230

Section 1– MWF 1400-1450

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Office Hours:

MTuF 10:30-11:30 a.m. or by appointment

This Class (Lecture 3):

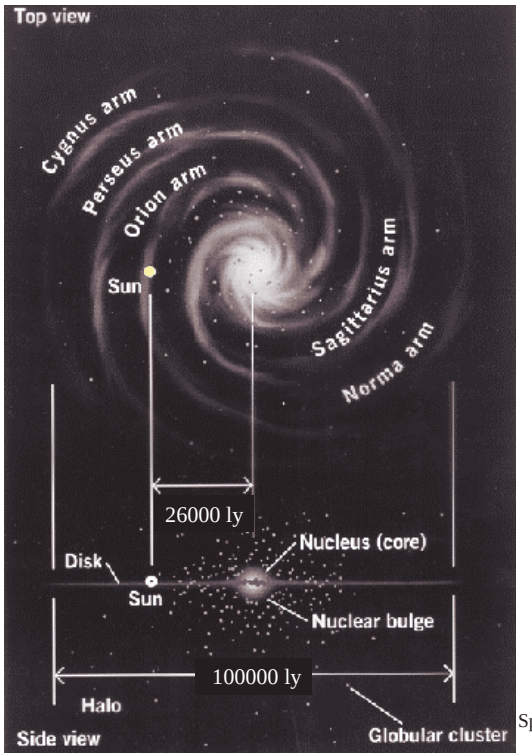
Cosmology and the Origin of Elements

Next Class:

The Early Galaxy and the First Stars

Outline

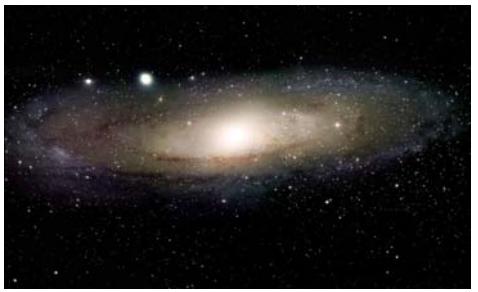
- The fate of the Milky Way.
- Cosmology. How old is the Universe?
- The seeds of galaxies.
- The early Universe was a supercollider.
- Big Bang Nucleosynthesis
- Cooling into normal stuff.
- What is the probable fate of the Universe?
- How does the lack of metals in the early Universe impact life?
- The Early Milky Way.



Our Galaxy

Fate of the Milky Way: It's coming right for us!

- What will happen to the Milkyway?
  - It will continue to grow as it cannibalizes the smaller orbiting galaxies.
  - The Andromeda galaxy is on a collision course.
  - Eventually (billions of years) we will end up a combined galaxy.
  - Probably look like an elliptical galaxy.

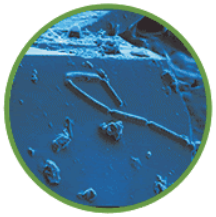


http://www.seds.org/messier/small/m87.gif

Defining Life

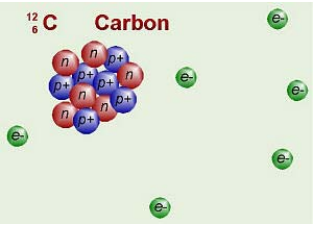
As we will discuss later, defining life is very difficult. Traditional attributes of life define it as:

my



Elements of Life

- Carbon is the most important element in life on Earth with oxygen and nitrogen coming in a close second. But where did they come from?
- To understand this question, we need to address the origin of the Universe.
- In other words, Cosmology.



http://biology.clc.uc.edu/courses/bio104/atom-h2o.htm

The Universe

- Began with a Big Bang
  - 13.7 billion years ago
- Still expanding and cooling
  - The rate of expansion is known
- It is BIG
  - As far as we are concerned, it is infinite in any direction
- The universe is homogeneous and isotropic
  - **Homogeneous** - The same "stuff" everywhere
  - **Isotropic** - The same in all directions
- Our place in the Universe is not special
  - Extension of the Copernican revolution
- The center of the Universe is everywhere or nowhere!

What do you think?

- The Universe is expanding, how do you feel about that?

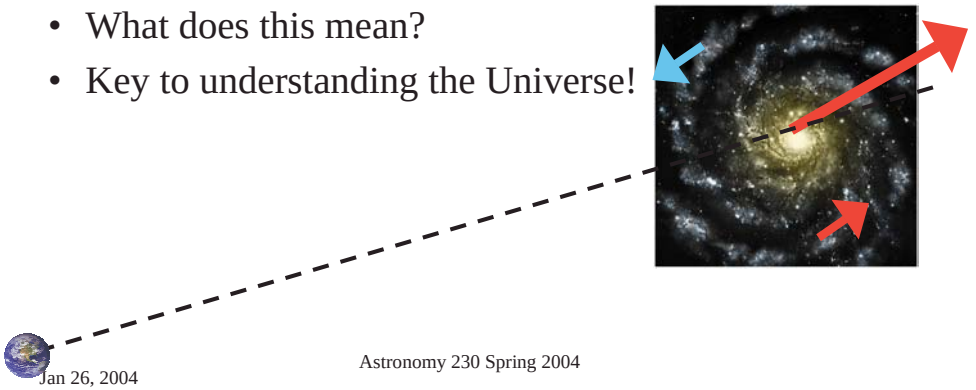
How are Galaxies Moving?

It's 1928 and Edwin Hubble is measuring how galaxies move. What does he find?

a) More galaxies receding than approaching.
b) More galaxies approaching than receding.
c) About equal numbers of each.

Redshift of Galaxies

- Most galaxies are moving away from us.
- The farther away, the faster they are moving away.
- Or $V = H_o \times D$
  - $H_o = 72$ km/s /Mpc
- What does this mean?
- Key to understanding the Universe!



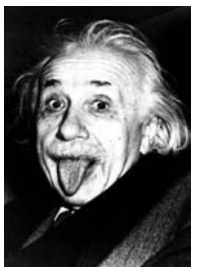
Apply it?

- In a homogenous Universe, what does the farther away the faster they move away mean?
- Draw it.

Interpretation: View of the Universe

Egoist view– We are at the center of the Universe.

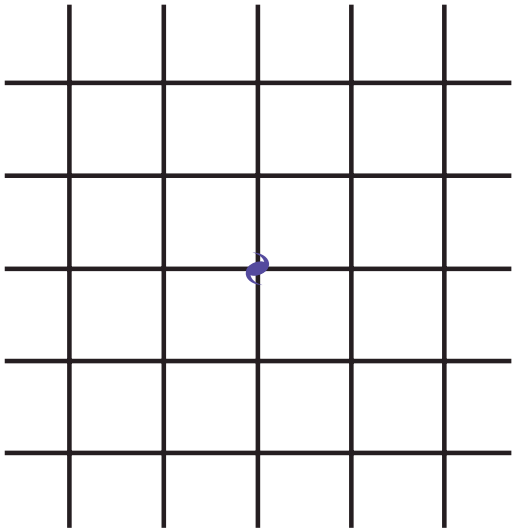
Einstein's view– The Universe is expanding, and there is no center!



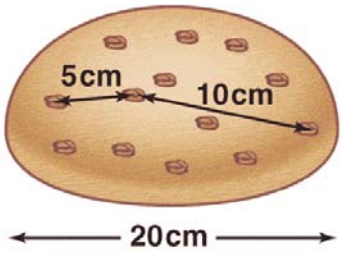
The Expanding Universe

- To describe the motion of all the galaxies in the Universe, we must use General Relativity (due to the gravity effects)
- General Relativity tells us that we live in an *expanding Universe*.
- In other words, space is stretching in all directions. This completely explains Hubble's Law.
- Overhead demo.

Dude, The Universe is Expanding.



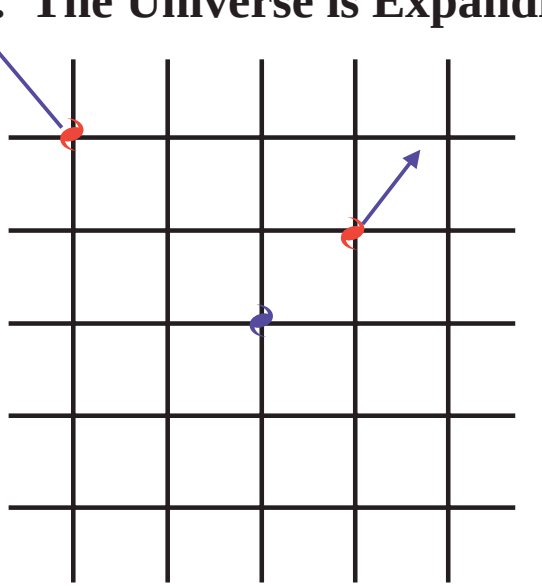
Analogy– Raisin Bread



Raisins stay the same size.

~~Expanding into What?~~

Wow. The Universe is Expanding.

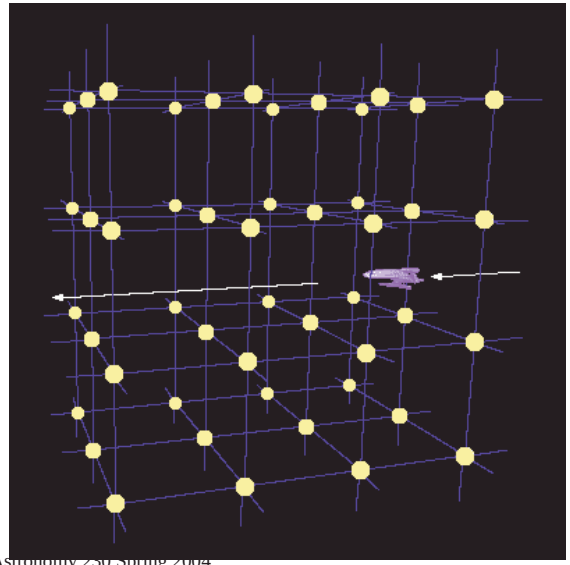


Reality

- The analogies are just to help us visualize, don't get stuck in the specifics.
- The Universe has no center
- The Universe has no edge
- Concept of time and space began with the Universe, can not apply the concepts so easily.
- The Doppler Effect is not the reason that galaxies are redshifted. As space expands, it stretches the light.

The Edge of the Universe?

- If the Universe consisted of only 48 stars?
- The spaceship, would never really see the edge of the Universe.



http://www.anzwers.org/free/universe/bigbang.html

Living in an Expanding Universe

Consider a large "box" containing many galaxies

- Total mass in box today: ***M***
- Total volume in box today: V_{today}
- ***Density today*** $= M/V_{today}$

How does the density of the Universe change with time? As Universe expands:

- ***M*** stays the same
- ***V*** becomes larger
- Density ***M/V smaller***

Density changes with time!

- Universe was denser the past
- Universe will be less dense in future

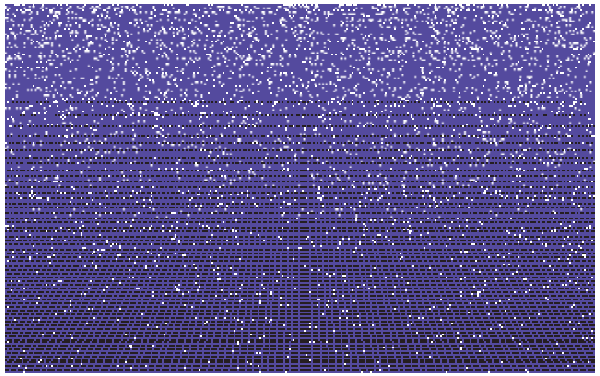
Putting it all together:

1. Earlier Universe was more dense
2. Earlier Universe was hotter.
3. The Universe is expanding.

The origin of the Universe can be described by the idea of the Big Bang.

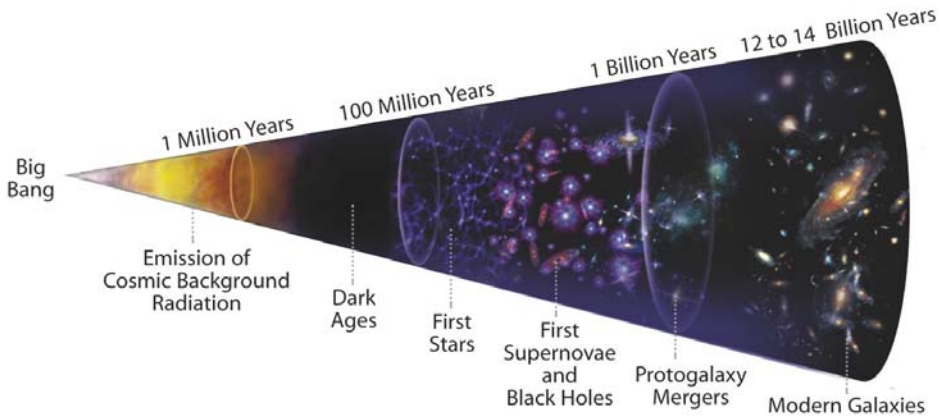
The Big Bang

- Occurred everywhere at once.
- Not an explosion into empty space.
- The Universe was suddenly filled with matter– hot and dense.
- A point, or infinite.
- The beginning of time and space.
- Expanding and cooling, eventually forming the stars and galaxies we see today.



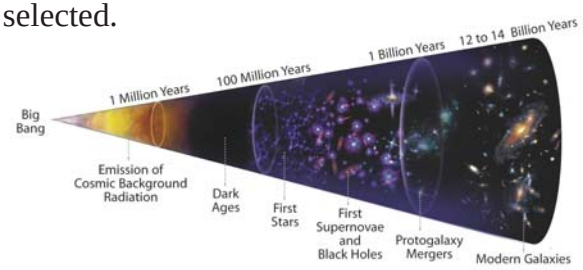
http://www.anzwers.org/free/universe/bigbang.html

The Backward Ride



The Big Bang

- In the 1940s, extrapolating on Hubble's Law, George Gamow proposed the the universe began in a colossal "explosion" of expansion.
- In the 1950s, the term BIG BANG was coined by an unconvinced Sir Fred Hoyle who tried to ridicule it.
- In the 1990s, there was an international competition to rename the BIG BANG with a more appropriate name, but no new name was selected.

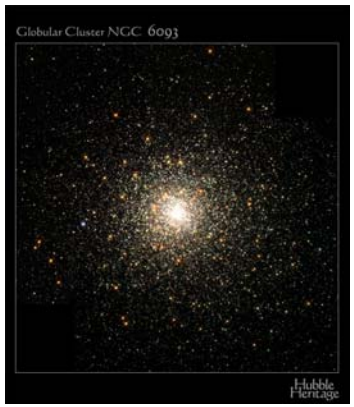


The Age of the Universe

Other methods to date the Universe:

- Radioactivity in Rock
  - uranium decays to lead
  - decay is "clock": tells time since uranium made in star
  - age > 10 billion yrs

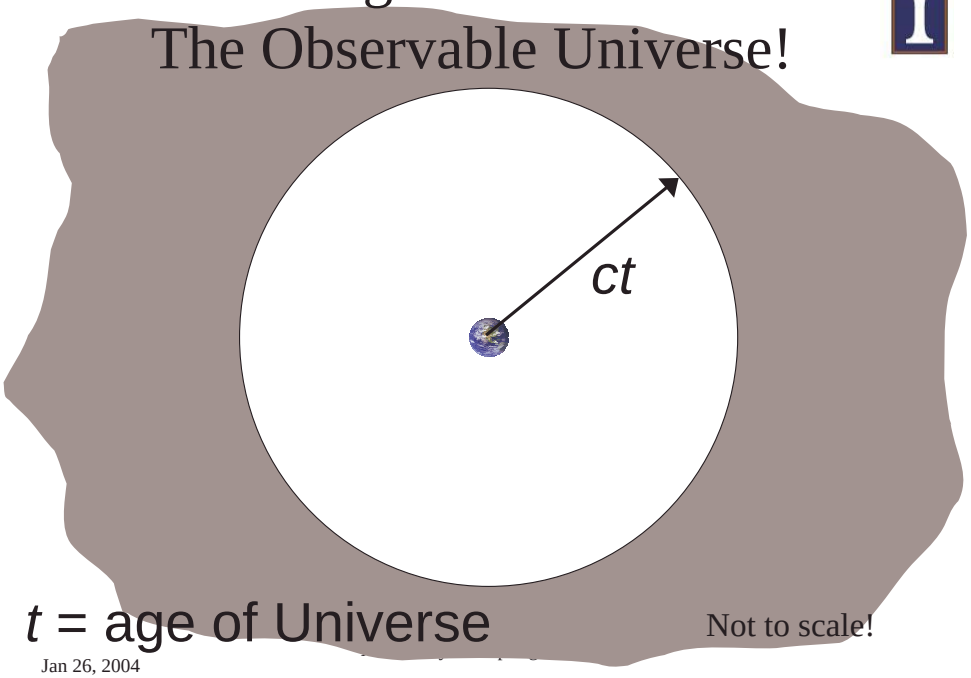
- Globular clusters
  - oldest stars
  - age about 13 billion years



Best estimate (WMAP good to 1%):

- Age t = 13.7 billion years

Looking Back in Time: The Observable Universe!

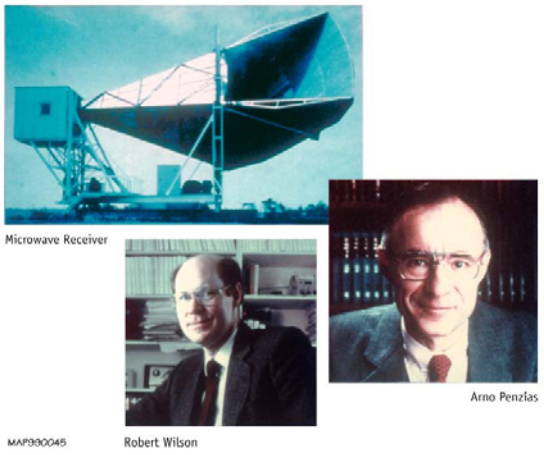


t = age of Universe

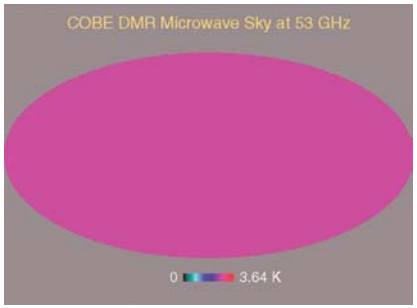
Not to scale!

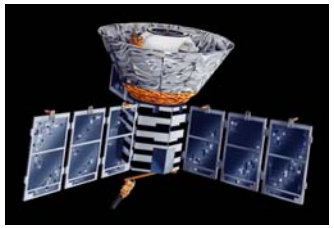
The Early Universe was *HOT*!

- If the early Universe was so hot, we should be able to see the blackbody radiation, redshifted. Right?
- Yep! It's shifted down to the microwave. Called the Cosmic Microwave Background.
- First detected by Robert Wilson and Arno Penzias.



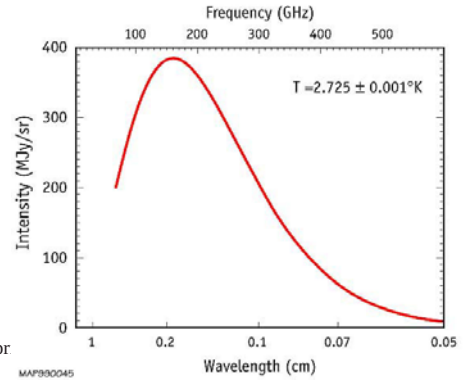
In Fact a Rather Uniform Blackbody

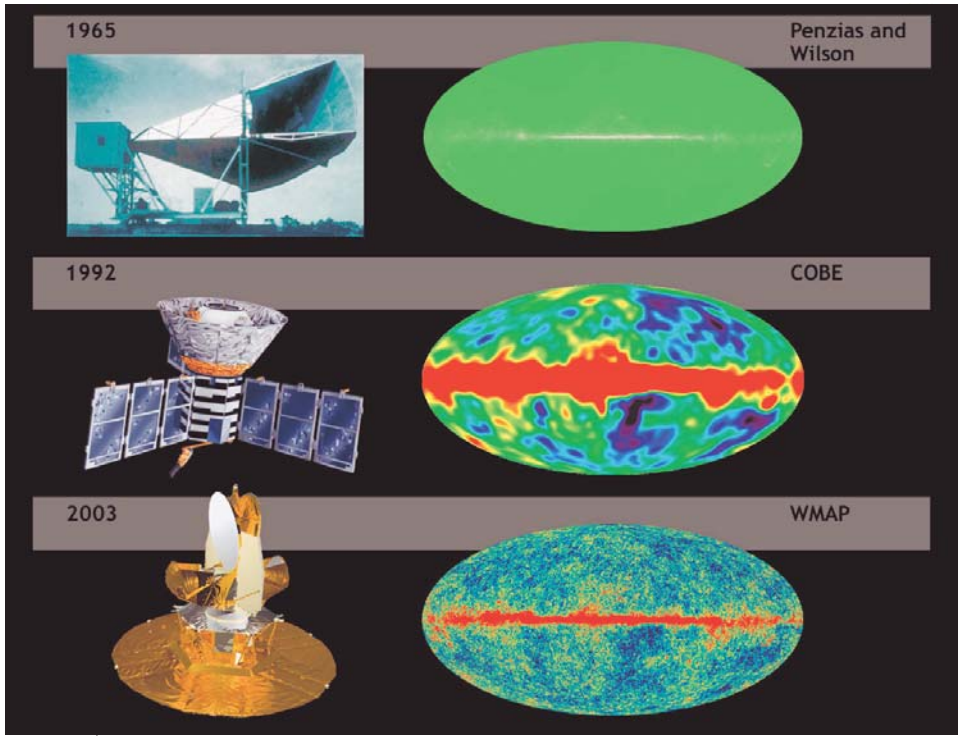




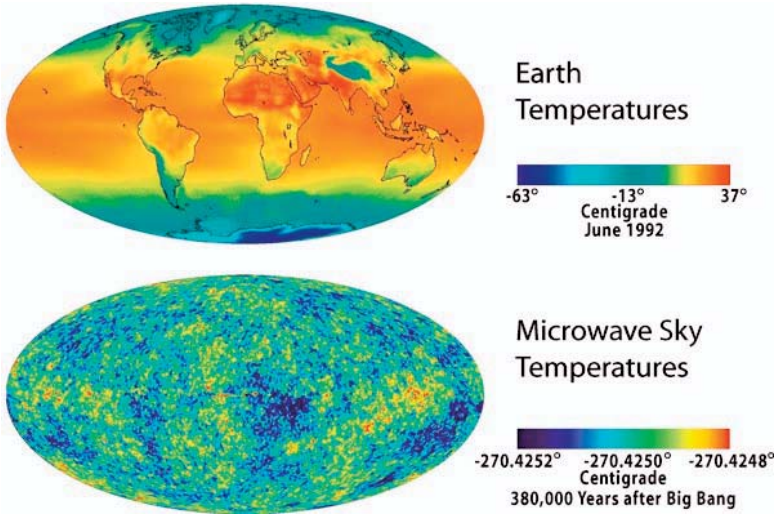
Cosmic Background Explorer (COBE) satellite (launched 1989)

$T \approx 3$ K





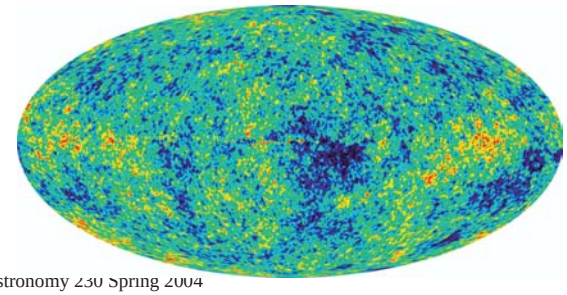
WMAP took a "baby picture" of the Universe



The Seeds of Galaxies

These small perturbations are the fluctuations (better than 1 in a 1000) that caused the large scale structures we see today. This is what formed the galaxies. All of this happened only 380,000 years after the Big Bang.

http://map.gsfc.nasa.gov/m_ig/030651/030651b.mov



THE VERY EARLY UNIVERSE

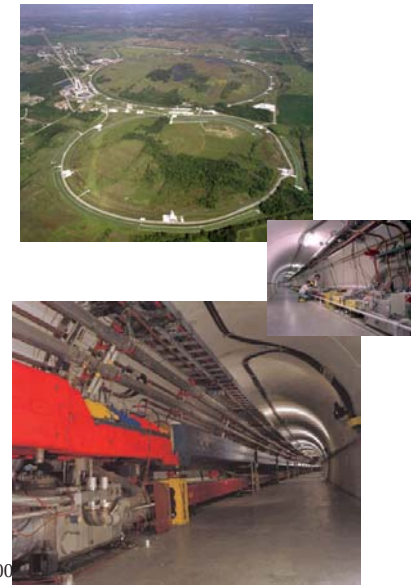
Since Big Bang works well so far, we have confidence to think about times earlier still:

t << 1 sec !

- Temperature and energies are ***ultrahigh***

Q: How to probe such high energies?
Hint: it's in the Great State of Illinois

Fermilab



INNER SPACE / OUTER SPACE

Fermilab is a telescope!

Probes conditions in Universe at 10^{-12} s

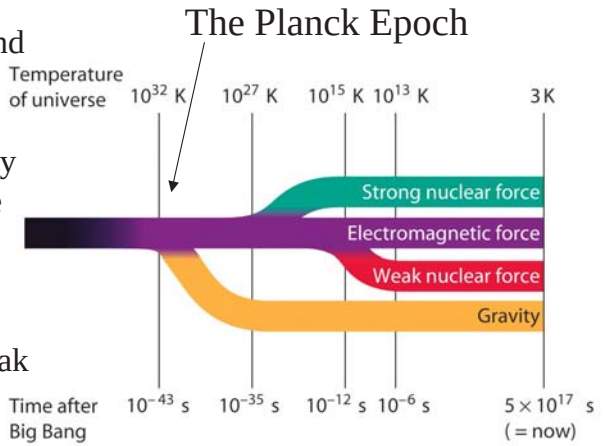
…but also…

"The Universe is the poor man's accelerator"

Probes conditions inaccessible at laboratories

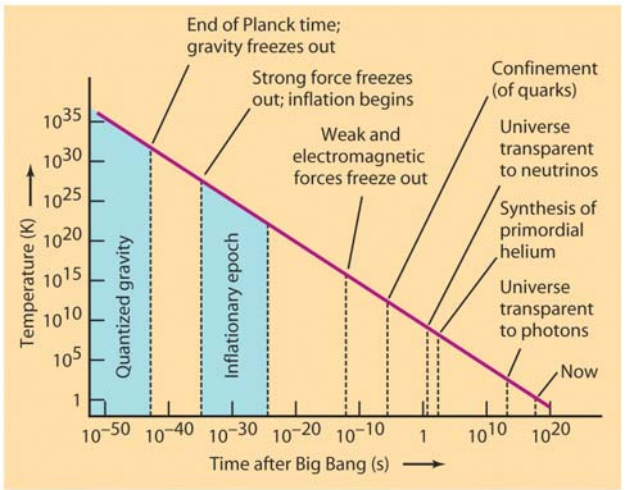
How do we understand the early Universe?

The first time after the Big Bang that we can understand is about 10^{-43} seconds and after. For anything before that we would need a theory of everything. At that time all the 4 forces are equivalent– Gravity, Electromagnetic, Strong Nuclear Force, and the Weak Nuclear Force.



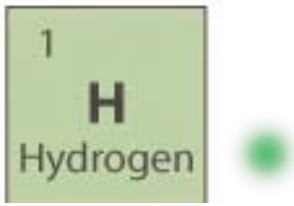
Inflationary Period and On

- Universe went through period of extremely rapid expansion early in its history (before 10^{-32} sec)
- Expansion by more than factor of 10^{50}
- **10^{-12} second:** electromagnetic and weak forces separate
- **10^{-6} second:** free quarks condense into protons and neutrons
- **1 second:** Universe becomes transparent to neutrinos



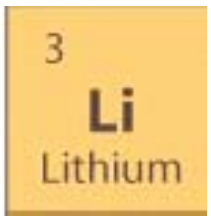
Big Bang Nucleosynthesis

After about 3 seconds, the temperature falls to 10^9 K and protons and neutrons can "shack-up" to form the first light elements. The Universe is a supercollider.

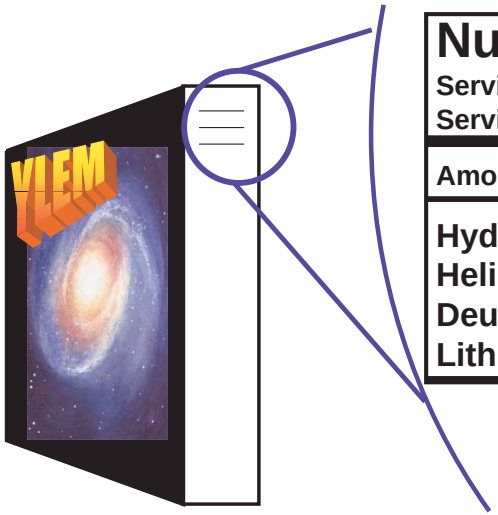


(a proton)

Also: Deuterium



End Result:
Big Bang Correctly Predicts Abundances



Nutrition Facts

Serving Size 1 g
Servings Per Universe many many

Amount Per Serving

Hydrogen	**0.75 g**
Helium	**0.25 g**
Deuterium	**10^{-4} g**
Lithium, etc.	**10^{-10} g**

What is the Universe's Fate?

Today: Universe is expanding. What next?
Competition: gravity vs inertia


or

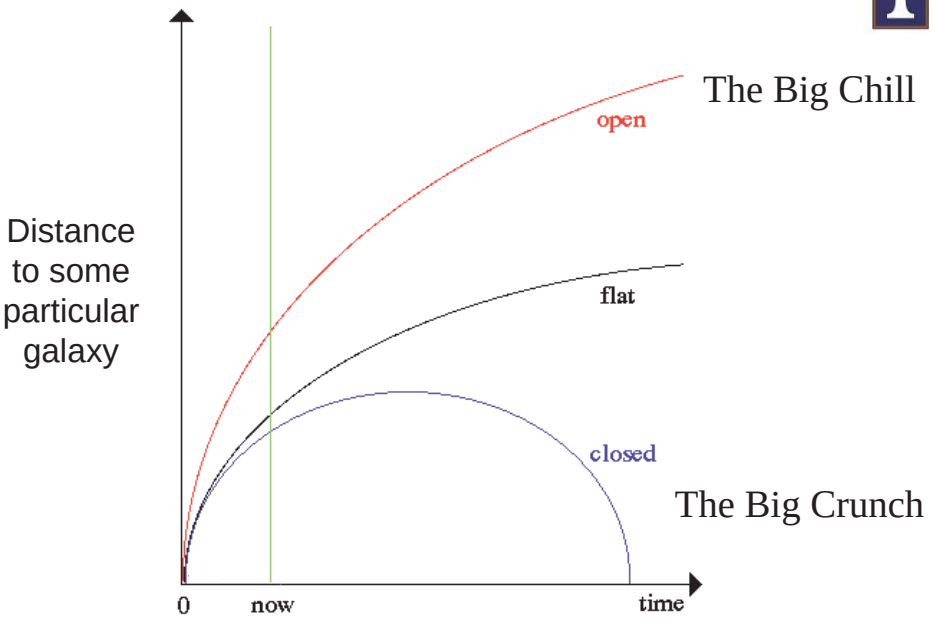

Compare: pop fly!
- Quantitative question:
- Launch speed vs speed to escape Earth

For Universe:
- Gravity: galaxy mass density ρ (Greek rho)
- Inertia: expansion $\rightarrow \rho_{critical}$

Both are observable!

Fate $\rightarrow$ **quantitative** question :
- if $\rho < \rho_{critical}$ expand forever
- if $\rho > \rho_{critical}$ expansion halts, collapse

What kind of Universe do we live in?



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A Census of Matter

% of critical density

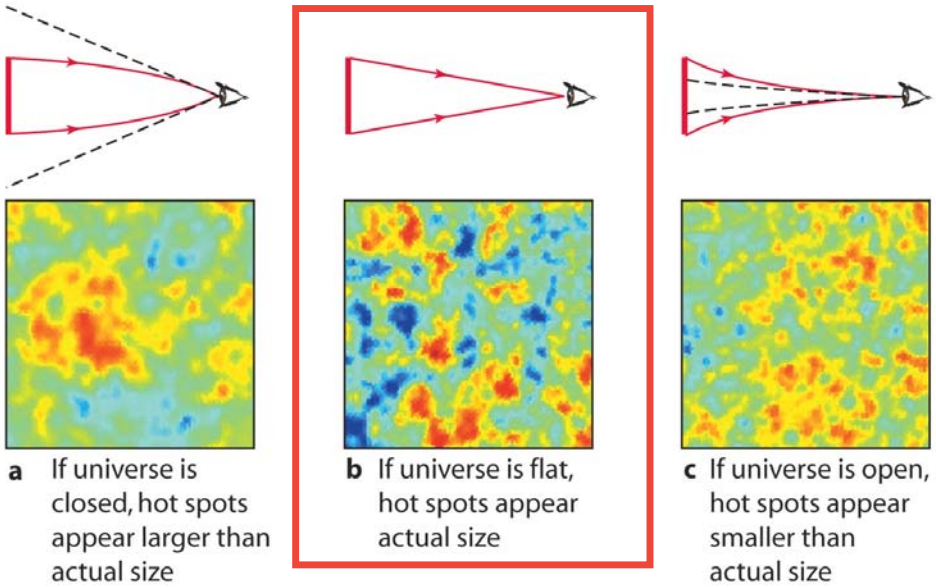
22% Dark matter
Needed to explain:
galaxy rotation curves
clusters of galaxies

4.5% Ordinary matter
Made of protons, neutrons, and electrons

<1.5% Neutrinos

28% Total Not enough to close the Universe

CMB Measurements: Universe is Flat



a If universe is closed, hot spots appear larger than actual size

b If universe is flat, hot spots appear actual size

c If universe is open, hot spots appear smaller than actual size

The Big Chill

- The Universe will just barely expand forever, getting cooler and cooler.
- If all of the mass, dark+regular, isn't enough, then there is something else afoot.
- The fate of the Universe is really dependent on the amount of matter and energy in the Universe. $E = mc^2$
- So, a new type of energy called Dark Energy (repulsive gravity and not related to Dark Matter) exists. The dark energy is dominating the fate of the Universe.
- 70% of the Universe is this dark energy.

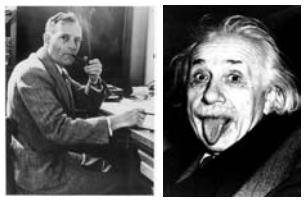
From the Home Office in Urbana, IL

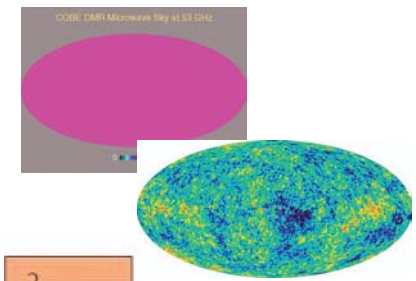
Top 3 Reasons We Believe in the Big Bang

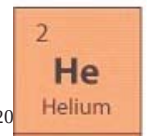
3. Hubble: v=HR
   + Einstein General Relativity
   = Big Bang and expanding Universe with age t = 13.7 billion yrs

2. Cosmic microwave background
   Primordial fireball– Big Bang working at t = 400,000 yrs
   - Nearly uniform temperature in all directions early Universe was very homogeneous
   - Tiny temperature fluctuations: "seeds" of galaxies

1. Big Bang Nucleosynthesis
   H and (almost all) He come from Big Bang
   Big Bang model working at t = 1 s







The History of the Universe in 200 Words or Less

Quantum fluctuation. Inflation. Expansion. Strong nuclear interaction. Particle-antiparticle annihilation. Deuterium and helium production. Density perturbations. Recombination. Blackbody radiation. Local contraction. Cluster formation. Reionization? Violent relaxation. Virialization. Biased galaxy formation? Turbulent fragmentation. Contraction. Ionization. Compression. Opaque hydrogen. Massive star formation. Deuterium ignition. Hydrogen fusion. Hydrogen depletion. Core contraction. Envelope expansion. Helium fusion. Carbon, oxygen, and silicon fusion. Iron production. Implosion. Supernova explosion. Metals injection. Star formation. Supernova explosions. Star formation. Condensation. Planetesimal accretion. Planetary differentiation. Crust solidification. Volatile gas expulsion. Water condensation. Water dissociation. Ozone production. Ultraviolet absorption. Photosynthetic unicellular organisms. Oxidation. Mutation. Natural selection and evolution. Respiration. Cell differentiation. Sexual reproduction. Fossilization. Land exploration. Dinosaur extinction. Mammal expansion. Glaciation. Homo sapiens manifestation. Animal domestication. Food surplus production. Civilization! Innovation. Exploration. Religion. Warring nations. Empire creation and destruction. Exploration. Colonization. Taxation without representation. Revolution. Constitution. Election. Expansion. Industrialization. Rebellion. Emancipation Proclamation. Invention. Mass production. Urbanization. Immigration. World conflagration. League of Nations. Suffrage extension. Depression. World conflagration. Fission explosions. United Nations. Space exploration. Assassinations. Lunar excursions. Resignation. Computerization. World Trade Organization. Terrorism. Internet expansion. Reunification. Dissolution. World-Wide Web creation. Composition. Extrapolation?